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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Instruments
for Automotive Engine
Tune-up

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Instruments for Automotive Engine Tune-up

TO TUNE-UP, according to the dictionary, means "to bring a musical instrument to the proper pitch for playing." No true musician would ever attempt to play on an instrument which is not in tune. Hence, the tuning-up activities which precede musical programs. This tuning-up procedure is accepted as being such a necessary adjunct to optimum musical performance that we never stop to think of the discords and poor performance, even with the best of instruments and musicians, which might result were the instruments to be out of tune.

Automotive engines, likewise, must be properly "tuned" in order to avoid the equivalent of musical discords which would manifest themselves as "ping," reduced power, poor fuel economy, operational roughness, etc.

IN DISCUSSING this subject of engine tune-up, the authors compare the automotive engine to a stringed musical instrument. Another comparison would be to liken the engine to the human body as to precision of construction. Both function at their best when kept in perfect adjustment, when fueled with "digestible" fuel of the correct calorie or BTU value, when driven with proper regard for output capacity. The doctor checks our bodies for output capacity. The automotive mechanic checks our car engines. When we keep both tuned-up to the right balance the enjoyment of living and driving is stimulating.

Just as a musical instrument may get out of tune as a result of use, so may an engine. The musician tunes his instrument to a standard one or more notes sounded by another instrument which is known to be in tune. Similarly, engines must be tuned to standards to deliver the performance built into them by the manufacturers. Although engines are not usually tuned or adjusted to standards as represented by engines known to be in proper adjustment, many standards are available in the form of manufacturers' specifications. However, means must be available to determine whether or not the engine is adjusted to specifications. The means are, of course, the instruments used for engine tune-up.

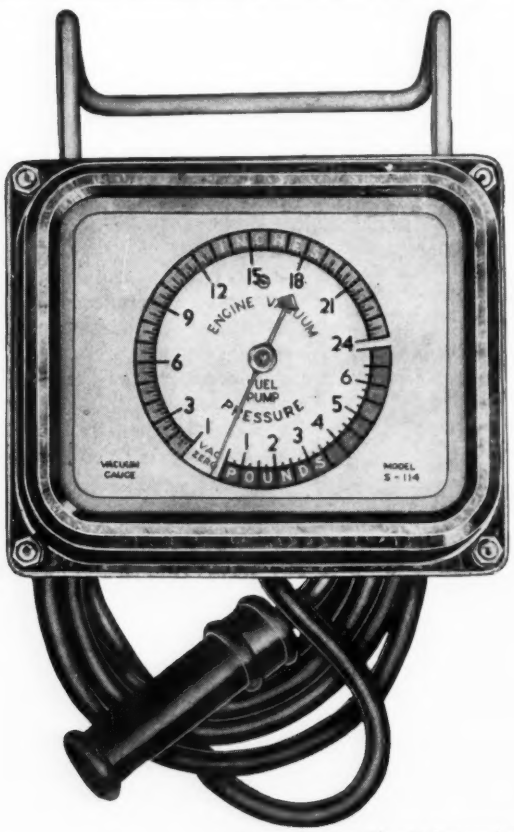
When the musician tunes an instrument he makes only minor adjustments and does not attempt to make major repairs at the time. He does, nevertheless, use the observations made while tuning-up to detect whether or not major repairs are required. Furthermore, he recognizes that there is little purpose in tuning the instrument if major repairs are required since, even after tuning in such circumstances, the quality of performance will be impaired and will not be equivalent to that produced by an instrument in satisfactory operating condition. Likewise, in the case of an engine tune-up, observations are made to detect whether or not the engine is in need of major repairs. If extensive repairs are required, minor tune-up adjustments may be made but the engine's performance will be somewhat less than that which might be expected of it. In any event, diligence is required in interpreting the observations in terms of repairs and adjustments which are indicated and a definite sequence in making tune-up observations should be followed. As a rule, mechanical observations should be made first, followed by analyses of the electrical and fuel systems in the order named. Systematic analyses are mandatory for best results.

INSTRUMENTS FOR MECHANICAL OBSERVATIONS

As differentiated from relatively minor repairs, such as replacement of distributor breaker points or cleaning of the carburetor, the major repairs are generally thought of as including such items as grinding of valves or installation of new piston rings. To determine if any of the latter are required, checks of intake manifold vacuum and cylinder compression pressures may be made with appropriate instruments.

Intake Manifold Vacuum Measurement Instruments

Either a Bourdon tube type gage, see Figure 1, or a manometer (mercury-filled) may be used to measure intake manifold vacuum, the connection usually being made at the windshield wiper hose fitting on the intake manifold. As shown in Figure 2, the Bourdon tube type gage incorporates a spring tube which is open at the end to be connected to the engine and closed at the other end. It is elliptical in cross-section and is bent into a circular arc.



Courtesy of Sun Electric Corporation

Figure 1 — Combination engine manifold vacuum-fuel pump pressure gage.

When internal vacuum is applied to the tube, it tends to bend even more. A linkage is attached to the Bourdon tube at the closed end in such a fashion that the amount of deflection of the tube, which is proportional to the vacuum applied, is registered by the pointer on the instrument dial. The dial may be calibrated by noting the position of the pointer when various known amounts of vacuum are applied. Generally, the instruments are calibrated in inches of mercury when intended for use in tune-up work.

A manometer is simply a U-Shaped tube (in some cases a single leg is used) which is approximately half filled with mercury. The difference in atmospheric pressure and the negative pressure of the intake manifold is directly determined on the manometer scale from displacement of the mercury.

Table I lists several classifications of vacuum gage readings which may be encountered and corresponding possible causes of the readings.

TABLE I

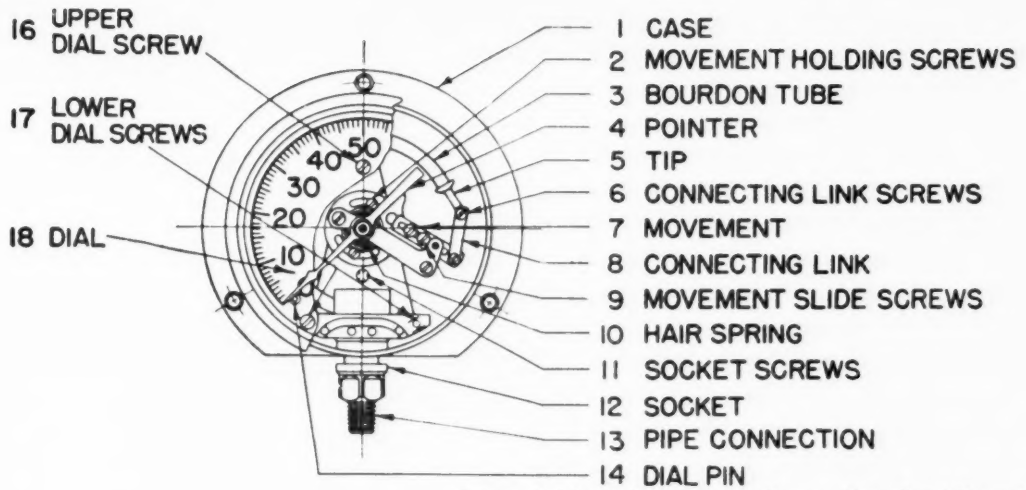
Typical Types and Causes of Vacuum Gage Indications

*Vacuum Gage Symptom**	*Possible Cause*
Low vacuum when idling	Leaky intake valves Burned valves Sticky valves Leak in intake manifold Worn or stuck piston rings or too large piston clearances Incorrect spark timing Incorrect carburetor adjustment Exhaust line restriction
Rapid vibration of indicating hand at low speeds only	Worn intake valve guides
Rapid vibration of indicating hand at high speeds only	Weak valve springs
Periodic indicating hand drop when idling	Burned valves Too little tappet clearance Sticky valves
Slow drift under 17-21" mercury when idling	Faulty carburetion adjustment Spark plug gaps too small

* At idling speed, vacuum should be of the order of 17-21" mercury at sea level with the engine at operating temperature. Vacuum should be fairly steady at 5-10" mercury upon cranking with closed throttle.

Compression Pressure Measurements

These measurements are made with Bourdon tube type gages, see Figure 3, which are constructed substantially the same as the manifold vacuum gage previously described. The essential difference is that when pressure is applied to a Bourdon tube, it tends to straighten out. Therefore,



Courtesy of Ashcroft Gauge Division; Manning, Maxwell and Moore, Inc.

Figure 2 — Cut-away view showing construction of a Bourdon tube gage.

the pointer linkage is arranged to register the tube deflection on the gage dial in terms of the pressure (pounds per square inch in the case of a compression pressure gage) applied to the tube. In addition, a compression pressure gage incorporates a check valve installed between the fitting for connecting the gage to the engine and the Bourdon tube. This valve acts much the same as an automobile inner-tube valve; that is, pressure can be applied to the gage and held in it until the check valve is released. This is necessary since compression pressures are usually taken by removing all spark plugs from the engine, connecting the gage to one spark plug hole and cranking the engine with the starter, the ignition being off and the throttle either closed or open. As the engine comes up to cranking speed, pressure is alternately built up and released on successive compression and exhaust strokes. If a check valve were not installed, the gage would fluctuate wildly with each compression and exhaust stroke. With the valve, a relatively steady reading is obtained.

Compression pressures should be successively taken on all cylinders. The significance of some of the more common types of gage readings is shown in Table II.

Instruments for Engine Speed Measurement

The tachometers employed for tune-up work are usually connected with suitable leads to the ignition system and may utilize either an electrical or electronic circuit to effectively count the electrical impulses flowing in the system. As engine speed increases, the time interval between impulses becomes shorter and therefore more current flows to the indicating gage which may be a D'Arsonval galvanometer (to be discussed later) calibrated in revolutions per minute. A typical tachometer is shown in Figure 4.

Aside from measuring engine speed as such, tachometers may be used to check for air cleaner clogging by noting the increase in engine speed, at a given throttle setting, upon removing the air cleaner. Any appreciable increase in engine speed indicates that the cleaner requires servicing to reduce restriction to air flow.

TABLE II

Typical Types and Causes of Compression Gage Indications

*Compression Gage Symptom Upon Cranking**	*Possible Cause*
Slow pressure increase	Leaky valves Worn or stuck piston rings Excessive piston clearance
Sporadic pressure increase	Sticky valves
Low compression in one or more cylinders	Leaky valves Worn or stuck piston rings Excessive piston clearance
Low compression after using solvent on valve stems	Weak valve springs Burned valves Incorrect tappet clearance
Low compression after introducing oil to cylinder	Leaky valves
Essentially normal compression after introducing oil to cylinder	Worn or stuck piston rings Excessive piston clearance
Low compression in two adjacent cylinders	Leak in head gasket between cylinders

* There should normally be no more than 5-10 p.s.i. difference among cylinders at sea level with engine at or near operating temperature. The readings should also be within approximately ten per cent of the manufacturer's specifications.

Tachometers also may be used to check the performance of individual cylinders of an engine by shorting out one cylinder at a time and noting RPM drop. Less RPM drop in one or more cylinders indicates that these cylinders are developing less power than the others, possibly due to poor compression and/or faulty ignition.

INSTRUMENTS FOR ELECTRICAL SYSTEM OBSERVATIONS

Perhaps the most intricate portion of a tune-up analysis involves checking the electrical circuits. The automotive electrical system is generally comprised of five separate circuits, each having a specific purpose, which are inter-related to form the complete electrical system. The individual circuits include:

1. ignition system
2. generating system
3. starting system
4. lighting system
5. miscellaneous circuits (heaters, radios, clocks, etc.)

Courtesy of Sun Electric Corporation

Figure 3 — Engine compression pressure gage. Calibration is in pounds per square inch.

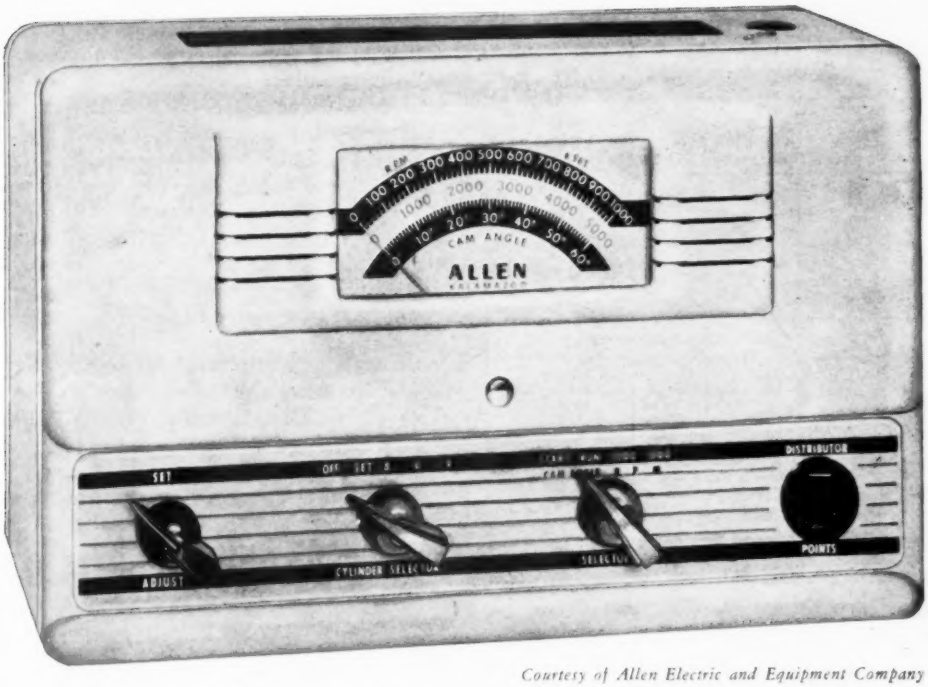
While it is beyond the scope of the present writing to discuss circuits other than the ignition system, it is of interest to note that some of the same type instruments required to check the operation of these circuits are also used, along with others, for the ignition circuits. Therefore, ensuing comments pertaining to certain instruments used for the ignition system also apply to these same instruments when used in connection with other circuits.

Operation of the Automotive Battery Ignition System

The essential components of an automotive battery ignition system, schematically shown in Figure 5, are the coil, distributor, condenser, spark plugs and connecting wiring; the current source is, of course, the battery-generator circuit. It is the purpose of the ignition system to deliver electricity to the spark plugs with the characteristics required to cause sparks at the spark plug electrode gaps. The spark must ignite the air-fuel mixture within the cylinder at the proper time in the engine cycle to secure optimum combustion of the mixture.

The ignition system is composed of two integrated circuits; that is, primary and secondary. The secondary is necessary because the voltage required to "fire" a plug may range from 5000 to 20,000 volts while the voltage available from the battery-generator system (primary) is only of the order of 4-7 volts. It is the purpose of the coil to change the low voltage to high voltage. This is done by creating a magnetic field in the coil core, causing its collapse by opening the primary circuit and thus inducing high voltage in the secondary coil windings. It is the purpose of the distributor to not only distribute the high voltage current developed in the coil to the various plugs at the proper time in the engine cycle, but to also control operation of the coil. The former is accomplished by the distributor rotor which is positively driven from the engine camshaft and acts as a switch to turn the current on and off to the spark plugs; the latter is accomplished by the distributor breaker points which are actuated by cams on the rotor drive shaft and act to turn on and off the primary system current from the battery-generator system to the coil. Because of the nature of the electrical process carried out by the breaker points and coil, it is necessary to incorporate a condenser across the points. The condenser serves to assist the collapse of the magnetic field of the coil, prevent arcing of the breaker points and dampen oscillating currents set up in the primary circuit as the result of discharge of the coil.

As mentioned above, it is necessary to deliver

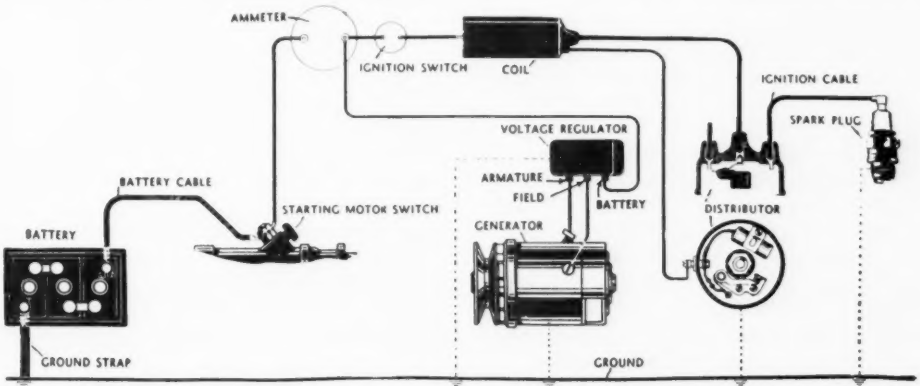


Courtesy of Allen Electric and Equipment Company

Figure 4 — Combination engine tachometer and distributor cam angle meter.

the spark at the proper time in the engine cycle and it is the function of the distributor to perform this job. The spark must be delivered at different times in the cycle, depending upon the speed at which the engine is operating and the power required of it. Accordingly, modern automotive distributors are designed with automatic units to change the time of spark occurrence in the cycle with both changes in engine speed and load. Spark timing changes required as the result of speed changes are often produced by centrifugal governor-type mechanisms which may be designed to make the spark occur at or near the timing for maximum full-throttle power at each speed while the changes to secure proper timing for part load operation are controlled by vacuum units since intake manifold vacuum is proportional to engine load at any given speed. Some manufacturers use only vacuum controls to change spark timing, the vacuum source being located in the carburetor.

In addition, the basic spark timing of an engine can be regulated to make the spark occur at a variety of different values as illustrated in Figure 6. From this figure it may be seen that changing the basic spark setting does not change the amount of spark advance provided by either the mechanical



Courtesy of The Chek-Chart Corporation

Figure 5 — Sketch illustrating components of a typical 6 volt automotive ignition system. Condenser is shown conventionally mounted in distributor.

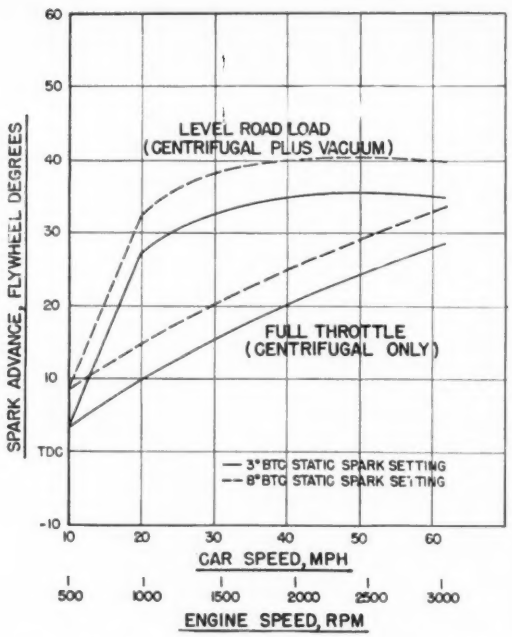


Figure 6 — Average of the distributor spark advance curves of three popular 1948 automobile engines.

(centrifugal) or vacuum advance units. Typical effects of spark timing on power, economy and the fuel octane number required for knock-free operation are illustrated in Figure 7. In addition, engine operating temperatures are considerably influenced by spark advance.

From the foregoing, it is evident that the performance of an engine greatly depends upon the proper functioning of each component of the ignition system and optimum performance can only be obtained if all components are adjusted and synchronized properly. A number of the instruments used to check these items are discussed below. Although different manufacturers may produce somewhat different instruments to perform the same function, the end objective — measurement of the performance of the ignition system and its components — is the same.

D'Arsonval Galvanometers

With the exception of distributor testers and variable spark gap devices, the instruments used to check the performance of the ignition system are usually comprised of D'Arsonval-type galvanometers installed in electrical circuits suitable to permit the required observations.

D'Arsonval galvanometers are, in essence, electric motors which rotate through a small arc. A sketch of a D'Arsonval galvanometer is shown in Figure 8. Briefly, a metal coil, with an attached pointer, is mounted on pivots which turn in jewel bearings. The coil is located in a magnetic field produced by a permanent magnet. The electrical energy to be measured is passed through the coil and, in so doing, it establishes another magnetic field about the coil. The reaction between the magnetic fields of the permanent magnet and the coil causes the coil to rotate in proportion to the energy passing through it. Some restraint on the rotation of the coil is provided by springs which return the coil and pointer to the zero position on the instrument dial when no energy is supplied to the galvanometer, and through which the current to be measured is transmitted to the coil.

Voltmeters, Ammeters and Ohmmeters

The voltmeter and the ammeter are basic variations of the D'Arsonval galvanometer, the voltmeter being used to measure the voltage or "pressure" under which electrical energy is flowing through a circuit and the ammeter to measure the rate of flow of the energy. Voltmeters are D'Arsonval galvanometers constructed with very high internal resistance in the coil circuit and, therefore, allow but very little energy to flow through them. They are always connected *across* the terminals between which the voltage is to be measured. Ammeters, on the other hand, are D'Arsonval galvanometers constructed with relatively low internal resistance and, accordingly, offer but little restriction to the flow of energy through them. They are always connected *into* the circuit in which the amperage is to be measured. While voltmeters may be connected into a circuit without damage to the meter, ammeters, due to their low internal resistance, must as a rule never be connected across a circuit otherwise they may be instantly burned out by the large amount of current which may pass through them. A voltmeter and an ammeter, installed in the same case, are illustrated in Figure 9.

The resistance to the flow of electrical energy through a piece of electrical equipment can be readily calculated from readings taken with voltmeters and ammeters by means of the expression $R = \frac{E}{I}$ (where R = resistance in ohms, E = voltage and I = amperage). However, it is often convenient in tune-up work to measure resistance directly. For this purpose, ohmmeters are used. Ohmmeters are constructed by placing a variable resistance (rheostat) in a circuit with a current source and a D'Arsonval galvanometer. To use an ohmmeter, the terminals or probes are short-circuited and the variable resistance adjusted to balance the circuit and make the instrument read zero. Then, when the resistance to be measured is connected across the probes, it causes current to flow in the circuit which creates unbalance. The amount of unbalance may be read on the instrument dial which is calibrated in terms of resistance.

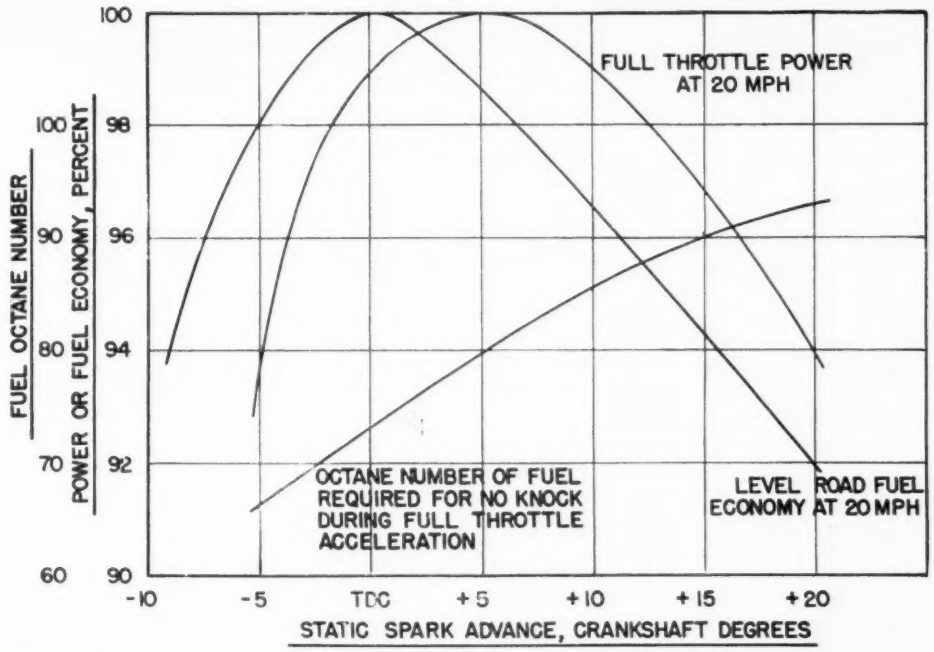


Figure 7 – Average performance of three popular 1948 automobiles as affected by spark advance. Note that too great spark advances result in decreased power and fuel economy and increased fuel octane number required to permit knock-free operation.

The same D'Arsonval galvanometer may be used to measure relatively wide ranges of voltage, amperage and resistance when connected with appropriate circuits (which include resistances, etc.) to the item to be measured. The significance of the indications of any electrical meter will, of course, depend upon the particular use to which the instrument is put. Therefore, it is extremely important to understand not only what the value of the particular item being measured should be, but also why the specified reading is prescribed as well as how it may be affected by either malfunctioning of the equipment being tested or by other components of the circuit. To mention only a few typical applications, voltmeters may be used to measure voltage drops through lines, ammeters to check starting motor current draw and ohmmeters to check not only resistance but also to locate short circuits, open circuits and grounds.

Instruments for Ignition Coil Tests

Both the primary and secondary windings of a coil may be checked for open circuits, grounds, insulation leakage and internal resistance using ohmmeter-type circuits similar to that described above. Internal resistance of the windings should be checked against the manufacturer's specifications. Due to the effect of temperature on wire resistance and insulation effectiveness, coils should be tested at their operating temperature; a coil may operate satisfactorily when cold and unsatisfactorily when hot.

Use of equipment which employs high frequency current is often desirable to detect shorted windings which may not be found with low frequency apparatus. A few shorted windings may not significantly reduce peak voltage but they will seriously decrease the duration of the spark, due to their dampening effect, with consequent reduction in engine performance.

In addition, variable spark gap equipment may be used to investigate coil operation. These instruments, see Figure 10, may consist of a motor-driven set of breaker points (the engine distributor breaker points may be alternately used if the coil is tested on the engine) to control the primary current in the coil and a spark gap which is installed between the secondary terminal of the coil and ground. The width of the gap can be varied and measured. The observation is made as to whether or not the coil being tested will produce a spark which will bridge a gap as wide as that bridged by the spark from the coil known to be in good condition.

Milliammeters (ammeters designed to measure very small amperages) are available to measure the current being supplied to the spark plugs; for smoothness of operation, all plugs should receive as nearly as possible the same amount of current. These instruments not only reflect the operation of the coil but also the entire ignition system.

Improper operation of the coil may result in

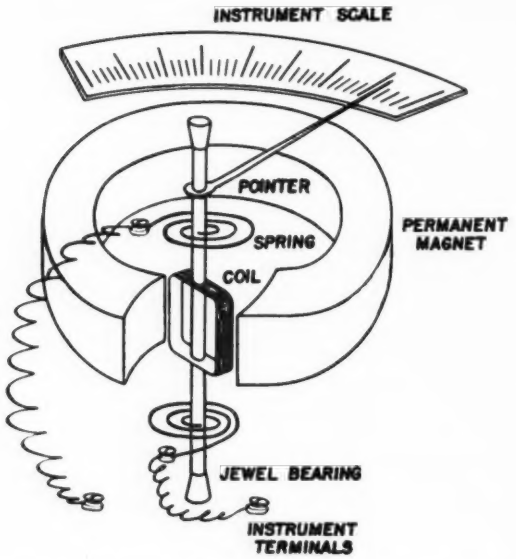


Figure 8 — Schematic diagram showing essential components of a D'Arsonval Galvanometer.

sparks at a plug which will be inadequate to ignite the air-fuel mixture in the cylinder with resultant loss of power and economy.

Instruments for Ignition Condenser Tests

Condensers may be tested for internal (series) resistance, insulation leakage and capacity using D'Arsonval-type galvanometers connected in appropriate circuits. Condenser test equipment may either be included in a group of instruments, as shown in Figure 11, or supplied separately. As in the case of coils, test results should always be checked for conformance with manufacturers' specifications.

Although a condenser may meet specifications in all respects, it is still possible for distributor breaker point pitting to occur. Pitting of one contact and the corresponding build-up of metal on the other contact is an electrolytic metal transfer process and may result from the manner in which the engine is operated. Slow speed or stop-and-go driving may cause this condition. When the pit appears on the negative contact, the capacity of the condenser is generally too low for the type operation to which the engine is subjected. When the pit is on the positive contact, too much condenser capacity is indicated. Point burning may be caused by excessive condenser resistance.

Instruments for Distributor Tests

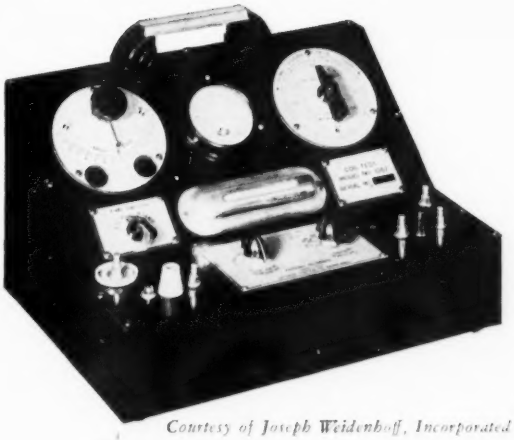
The instruments used for distributor tests are designed to check operation of the breaker points and the automatic spark advance mechanisms. A typical tester is shown in Figure 12. To accomplish this end, the machines provide a chuck in which to mount the distributor and a variable speed electric motor drive to rotate the distributor shaft. Moreover, instrumentation is normally provided to determine the speed of shaft rotation, the length of time the distributor breaker points are in contact as well as the amount of spark advance produced by the automatic advance mechanisms.

The length of time the breaker points are in contact, which is called dwell or cam angle, may either be indicated by a D'Arsonval galvanometer installed in an electrical circuit (similar to that used in tachometers) connected across the breaker points or it may be indicated, depending upon the particular type machine used, by the flashing of neon lights on a protractor, the lights being attached to the rotating distributor drive shaft and energized during the time the breaker points are closed. In either case, it is possible to determine whether or not cam angles are properly set. If cam angle is too small, there may be insufficient time for the coil to become energized and a weak spark may result with accompanying loss of engine performance. On the other hand, if cam angle is too great, the breaker points may close before the oscillating current, which is set up in the primary circuit by discharge of the coil, subsides. When this happens, the high voltage in the condenser, which has been charged by the oscillating current, may be discharged across the points along with current from the coil and point pitting will result.

It should be borne in mind that before proceed-

Courtesy of The Electric Heat Control Company

Figure 9 — DC Ammeter and DC Voltmeter installed in same case for convenience in use.



Courtesy of Joseph Weidenhoff, Incorporated

Fig. 10 — A variable spark gap tester.

ing to check the breaker points for dwell, breaker point spring tension should be measured inasmuch as this item has a considerable influence upon dwell; too little tension may contribute to excessive dwell and too much may cause the points to bounce upon closing and result in too little dwell and burning of the points. Moreover, before determining dwell, the primary circuit of the distributor should be checked for breaker point resistance. High resistance will indicate dirty contact points or loose electrical connections.

In both types of machines referred to above, neon lights are used to indicate the moment when the breaker points open, the time being expressed in degrees of crankshaft rotation. Therefore, upon increasing the speed of distributor shaft rotation, the degrees of automatic mechanical advance will increase in accordance with the characteristics of the distributor being tested; the amount of advance can be observed at various speeds and compared with the manufacturer's specifications. Moreover, upon applying various known amounts of vacuum to the distributor vacuum control unit, the effect of vacuum on advance can be measured and also compared to the values specified by the manufacturer. Distributors which employ a vacuum that has its origin in the carburetor can be tested on conventional distributor testing machines by applying the specified amount of vacuum and observing the advance produced.

In addition to the above observations, it is possible to utilize distributor testers to detect wear in the distributor. This may be done by noting fluctuations in cam angle or variations in patterns of the neon lights on the protractor, depending upon the particular tester being used.

Spark Advance Timing Lights

Timing lights are used to determine the time in the engine cycle at which the spark occurs. A typical timing light is illustrated in Figure 13. The lights flash whenever a secondary circuit current impulse passes through the line to which they are connected. These lights utilize the phenomenon of persistence of vision which is experienced when an object is viewed intermittently; upon viewing a cyclic motion at the same point in the cycle each time, the object appears to be motionless. Accordingly, when a timing light is directed at the rotating engine part that is marked for setting spark timing, such as the flywheel or vibration dampener, the point on the rotating part corresponding to the time at which the spark is occurring appears to be motionless relative to a stationary pointer mounted adjacent to the rotating part.

The reader will recall that some or the effects of spark timing on engine performance have already been briefly discussed.

INSTRUMENTS FOR CHECKING FUEL SYSTEM PERFORMANCE

As in the case of the ignition system, the fuel

Courtesy of Sun Electric Corporation

Figure 11 — Typical grouping of various tune-up instruments including combination vacuum-pressure gage, tachometer, exhaust gas analyser, dwell meter, coil and condenser test equipment.

Courtesy of Joseph Weidenhoff, Incorporated

Figure 12 — Equipment for testing distributors.

system has an exacting job to perform. It must pump the fuel, mix it with the proper proportion of air and deliver to the intake manifold the quantity of air-fuel mixture required by the engine under a wide variety of operating conditions to develop the power, economy, ease of starting, operating smoothness and flexibility expected by the driver. These functions are primarily handled by the fuel pump and the carburetor.

Fuel Pump Vacuum and Pressure Gages

The instruments commonly used to check fuel pump performance are vacuum and pressure gages. These gages may either be of the Bourdon tube type or they may be manometers as described above. A typical combination vacuum and pressure gage is shown in Figure 1. Such gages may also be used to measure exhaust back pressure when connected to the exhaust manifold.

To check fuel pump inlet vacuum, the gage may either be directly connected to the pump intake or attached to a tee fitting installed in the intake. A vacuum will be obtained with the engine at idling speed since the fuel tank is usually lower than the pump and the pump is sucking fuel from the tank. If vacuum readings less than 5-6" mercury are obtained, a leaking pump diaphragm or check valve may exist.

The pressure gage may be either attached to a tee fitting at the pump discharge to the carburetor or directly to the discharge. A pressure within the manufacturer's limits (usually 2-5 psi) should be obtained at idling speed to assure that adequate fuel is being supplied to the carburetor. If too low a pressure exists, it may cause loss of power and engine mis-firing; too low a pressure may be due to a leaky pump diaphragm and/or check valve. Too high a pressure, resulting from an improperly operating check valve, may cause carburetor flooding and attendant poor fuel economy if the pressure is sufficiently high to overcome the force exerted by the carburetor float and force the carburetor needle valve from its seat. The maximum pressure developed by the pump should be held for at least 1-2 minutes after stopping the engine. If not, there may be a leak in the pump diaphragm, a leaky check valve, leak in the line to the carburetor, too low a carburetor float level or a worn needle valve and seat.

Instruments to Check Carburetor Performance

Since the carburetor not only mixes fuel and air in definite proportions but also meters the resultant mixture to the engine, the instruments to check its performance should be capable of determining whether or not the carburetor is performing these operations satisfactorily. Due to the rather elaborate equipment required, it is not generally feasible outside of laboratories or shops specializing in carburetor repairs to measure the amount of air and

Courtesy of Allen Electric and Equipment Company

Figure 13 — Ignition timing light with attached electrical leads.

Courtesy of Cambridge Instrument Company, Inc.

Figure 14 — Thermal conductivity-type exhaust gas analyser.

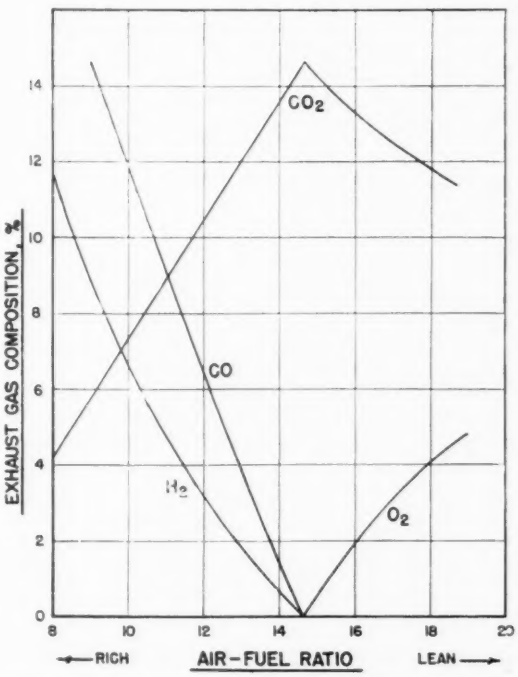
fuel passing through a carburetor. From this information it would be possible to calculate the ratio of fuel and air as well as the quantity of mixture flowing to the engine. It is possible, however, to estimate the ratio of air and fuel supplied by the carburetor with existing exhaust gas analysis instrumentation which is almost universally available wherever tune-up work is performed. An exhaust gas analyser is shown in Figure 14.

These instruments take advantage of the fact that when air and fuel are burned in different proportions, different amounts of the various exhaust gas constituents are formed. Figure 15 shows the variation in concentration of the various exhaust gas constituents in the exhaust of an engine when burning a motor gasoline over a range of supplied mixture ratios. The individual constituents each have different physical characteristics, such as density and thermal conductivity, and therefore, the physical characteristics of the overall exhaust gas vary with the concentration and properties of the constituents.

Nearly all commercially available exhaust gas analysers are constructed so as to either reflect exhaust gas thermal conductivity or compare the density of the exhaust gas with air. Representative relationships of exhaust gas thermal conductivity and density to supplied mixture ratio are shown in Fig. 16.

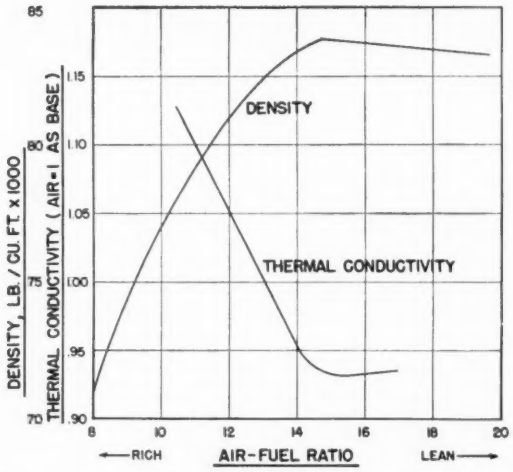
In the thermal conductivity type instrument, the exhaust gas is passed over a heated wire comprising one leg of a Wheatstone bridge circuit which is electrically balanced in the absence of exhaust gas. The exhaust gas passed over the wire changes the temperature of the wire, and therefore its resistance, in proportion to the ability of the gas to conduct heat away from the wire. The amount of bridge circuit unbalance created by the change in resistance is registered on the dial of the indicator, a D'Arsonval-type galvanometer, which has been previously calibrated in terms of supplied mixture ratio through knowledge of the relationship of supplied mixture ratio and thermal conductivity of the exhaust gas.

The relative density type instrument consists of two fans located in two separate chambers or compartments, one chamber being for air and the other for exhaust gas. These fans are motor driven at constant speed; each directs a blast of air or exhaust gas against a vaned stator wheel. These stators are connected through suitable linkages so that the difference in resistance to rotation produced by the difference in densities of the exhaust gas and air being pumped by the fans results in causing the linkage to move and a scale pointer to register the



From Paper by B. A. D'Alleva and W. G. Lovell; March, 1936 SAE Transactions, Vol. 38, No. 3

Figure 15 — Relationship of exhaust gas composition and supplied mixture ratio.



Density Curve from Paper by J. L. Dilworth, June, 1941 SAE Transactions, Vol. 48, No. 6

Thermal Conductivity Curve Courtesy of Cambridge Instrument Company, Incorporated

Figure 16 — Relationship of density and thermal conductivity of exhaust gas to supplied mixture ratio.

difference in densities on a scale which has been previously calibrated in terms of supplied mixture ratio on the basis of a relationship such as that shown in Figure 16.

While exhaust gas analysis may be used to study the overall operating condition of the engine, judgment should not be passed on the carburetor on the basis of exhaust gas analysis alone until it is certain that other items affecting engine performance are operating satisfactorily since exhaust gas composition is subject to not only variations in carburetion but also to variations caused by such factors as partial burning of the mixture due to incorrect spark timing. It should be borne in mind that attempts to compensate for poor overall engine operation through modification of the carburetor should not ordinarily be made.

The importance of maintaining correct mixture ratio is illustrated in Figure 17. Here it may be seen how power and economy are affected by mixture ratio. The temperature of valves and many other engine parts are also affected by mixture ratio and their susceptibility to premature failure enhanced by the relatively elevated combustion temperatures arising from too lean air-fuel ratios. Furthermore, the tendency toward detonation or "ping" is increased by running at lean mixture ratios. Too rich mixtures may produce spark plug fouling, dilution of crankcase lubricants, engine roughness at low speeds and poor fuel economy. Several causes of excessively rich and lean mixture ratios are given in Table III.

TABLE III

Causes of Lean Mixture Ratio:

Too small carburetor jets
Leak in windshield wiper hose and/or connections
Broken or cracked carburetor flange gasket
Broken or cracked intake manifold gasket
Cracked intake manifold
Worn carburetor butterfly valve shaft
Too low fuel pump pressure
Too low carburetor float level
Improper idling jet adjustment (at low speeds)

Causes of Rich Mixture Ratio:

Worn carburetor jets
Partially closed choke valve
Clogged air cleaner
Too high carburetor float level
Too high fuel pump pressure
Leaky carburetor needle valve assembly
Faulty carburetor acceleration pump adjustment
Improper idling jet adjustment (at low speeds)

CONCLUSION

New car performance can be extended far beyond the new car period if the average owner appreciates the precision which is built into his car and the benefits he can derive from respecting this construction. Easier starting, better mileage per gallon of gasoline, smoother running, less worry — all are obtainable, all contribute to banishing that tired feeling at the end of a drive. Periodic engine tune-up is the key. In this article we have tried to take the mystery out of this procedure. Simply because some of the instruments may look formidable does not signify that interpretation of their readings or adjusting the engine in line with the readings requires a string of college degrees. Good mechanics, good judgment and knowledge of engine design and the significance of the readings of tune-up instruments give the best results.

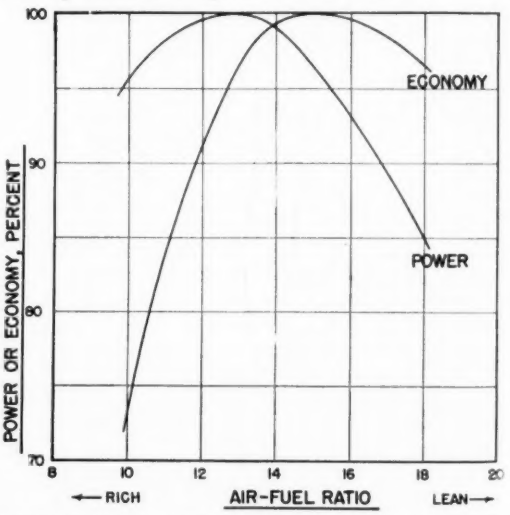


Figure 17 — Effect of mixture ratio on power and fuel economy of a typical engine.

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